Current Dependent Orbit Distortion and Beam-Lifetime Reduction in HERA-e

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This report describes observations in normal runs as well as dedicated experiments in HERA, 1998. During some luminosity runs it had been observed that the beam orbit in the electron machine changes with time by considerable amounts. In parallel lifetime reductions were observed and in some cases it could be suspected that those happened in connection with the orbit movements, due to aperture limits or so. The orbit motion results in the necessity to tune up luminosity from time to time and is at least unpleasant. However, the lifetime reduction which is sometimes dramatic, is a serious problem, and if it is caused (at least partially) by the orbit motion, this effect should be understood and removed. Dedicated experiments were done on October 10'th, and December 16'th.

1 Codes and Numerical Tools

In order to provide data with high time resolution a simple Visual Basic application has been written which allows to store electron orbits at a maximum rate of 1 Hz on disc. The program can be found under `S:\Projects\Vb\Orbcor\Test\Project1.exe`, and the data files are stored under `S:\tempdata\e_orbits\`. The regular data files have names like `d12_170853.dat`, where 12 is the day of the month and the other 6 digits give the time when the file was written. The files contain 277 x and y orbit positions of the beam, and current as well as lifetime in the last line. Everybody is welcome to use this program for other purposes, but don't forget to switch it off after usage and clean up the data folder from time to time!

After a run of several hours and typical orbit-writing-rates of 0.1 Hz several hundred orbits have been measured and are written to disc. The question arises how one can take advantage of such a large amount of data, especially in view of the suppression of statistical errors. If noticeable orbit movements are recorded it is important to decide whether there is only one underlying process that originates the orbit distortion, or if there are several independent effects. Under the keyword "Model Independent Analysis (MIA)" one can find a numerical method in the literature that attempts to attack these two questions[1]. The method is based on Singular Value Decomposition (SVD) of the orbit matrix. An orbit matrix $\mathbf{B}$ is built up of individually measured orbit vectors by arranging them in rows. In other words, the column index of $\mathbf{B}$ is a spatial index, it describes the location in the ring, whereas the row index is the number of the measurement, a time variable (if measuring intervals are equidistant). The SVD of this matrix results in three matrices, two orthogonal ones ($\mathbf{U}, \mathbf{V}$), and a diagonal one, $\mathbf{\Lambda}$.

$$\mathbf{B} = \mathbf{U\Lambda V^T}$$

$$\text{with :} \quad \begin{array}{rcl} \mathbf{U^T} &=& \mathbf{U}^{-1} \\ \mathbf{V^T} &=& \mathbf{V}^{-1} \end{array} \quad \text{, and} \quad \mathbf{\Lambda} = \begin{bmatrix} \lambda_1 & 0 & . \\ 0 & \lambda_2 & . \\ . & . & \lambda_n \end{bmatrix}$$

The orbit motion is thereby decomposited into a set of normalized spatial vectors (orbit patterns) in matrix $\mathbf{V}$, and a set of temporal vectors that describe the time development in matrix $\mathbf{U}$. The diagonal matrix $\mathbf{\Lambda}$ contains rms orbit variations, averaged both over the measurement time and the spatial distribution around the ring. Each number in $\mathbf{\Lambda}$ corresponds to one temporal vector and one spatial vector[2].

The key of the method is now that only a limited number of underlying physical processes result in orbit motions, i.e. the 277 BPM's in HERA will in general not vary independently, but according to certain correlation laws, as for instance a betatron orbit oscillation. The limited number of degrees of freedom in the system is reflected by the fact that only a small number of eigenvalues in $\mathbf{\Lambda}$ will have a large magnitude, and consequently only the corresponding temporal and spatial eigenvectors are relevant.

Our application of the described SVD method is to find out whether we can relate the observed HERA-e orbit motions to a single underlying effect or if there are several effects with possibly different behaviors vs. time. The number of significantly valued λ_i should answer this question.

2 Observations of Orbit Motions

During two dedicated experimental shifts, on October 14'th and December 17'th, the orbit motion was observed without collisions, with relatively high currents and without affecting the machine otherwise. The measurements where performed at 27 GeV with starting currents of 28 mA and 36 mA respectively. Spatially averaged rms orbit variations over times of two or three hours amount to 1.2 mm or

[1] Y.T. Yan et al., EPAC 1998, `http://www.cern.ch/accelconf/e98/PAPERS/WEP21G.PDF`

[2] Sometimes one talks about eigenvalues and eigenvectors here. The connection is that $\mathbf{V}$ contains the eigenvectors of the matrix $(\mathbf{B^T B})$ and $\mathbf{\Lambda}$ contains the square-roots of their eigenvalues. Similar $\mathbf{U}$ for $(\mathbf{BB^T})$.

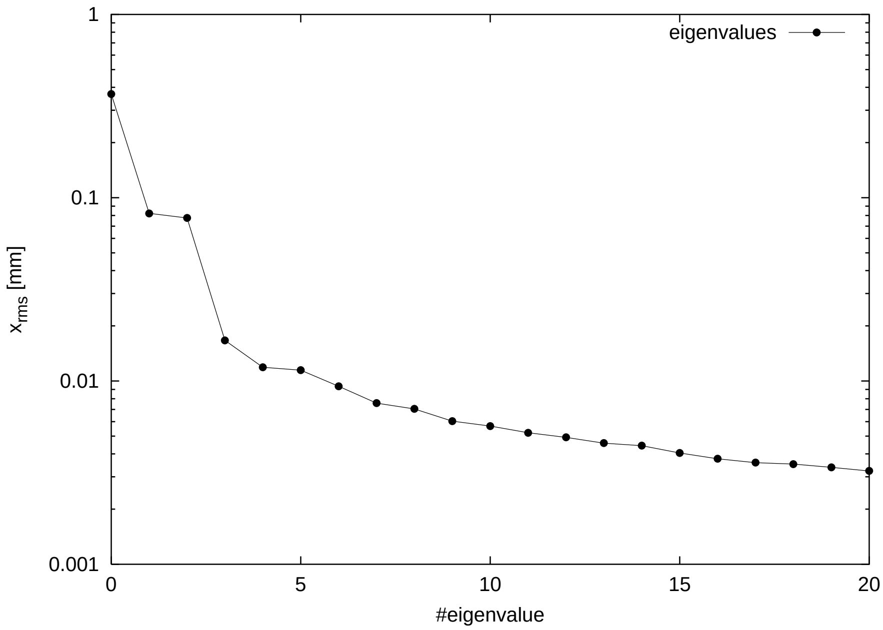

Figure 1: Magnitude of the first eigenvalues showing that one process is dominating the orbit motion. The second eigenvalue is already smaller than the first one by a factor 4.

more. In both cases only one major effect is causing the orbit distortion. Fig. 1 shows as an example the first largest eigenvalues from the SVD of the BPM matrix (measurement 14/10/98). The first temporal vector, scaled by the rms-value (1'st eigenvalue) shows the spatially averaged rms orbit deviation as a function of time. The curve exhibits a steep change in the beginning, saturates then, and decays later similar as the beam current. This is especially obvious when a part of the beam is kicked out (see Fig 3).

Knowing that only one process plays a role we would like to find out what it is and where it is located. The spatial vector corresponding to the largest eigenvalue looks like a betatron orbit oscillation, so one tries first to explain it by a single orbit kick. Indeed the pattern can be fit successfully by applying one most effective corrector, as is demonstrated by Fig. 2.

The location of the most effective corrector lies in the interaction region south. In order to find the position precisely one can compute the rms deviation of the best fit from the spatial vector as a function of the corrector position in betatron phase. In other words, a virtual corrector dipole is placed in fine steps at all possible phases and then varied in strength such as to fit the measured orbit best. The quality of the corrector position is evaluated by computing the rms deviation from the measured orbit. The real position of the kick should be found at the minimum of this curve. Of course the curve exhibits typically similar minima at π phase differences. Unfortunately, during the first measurement, the two monitors

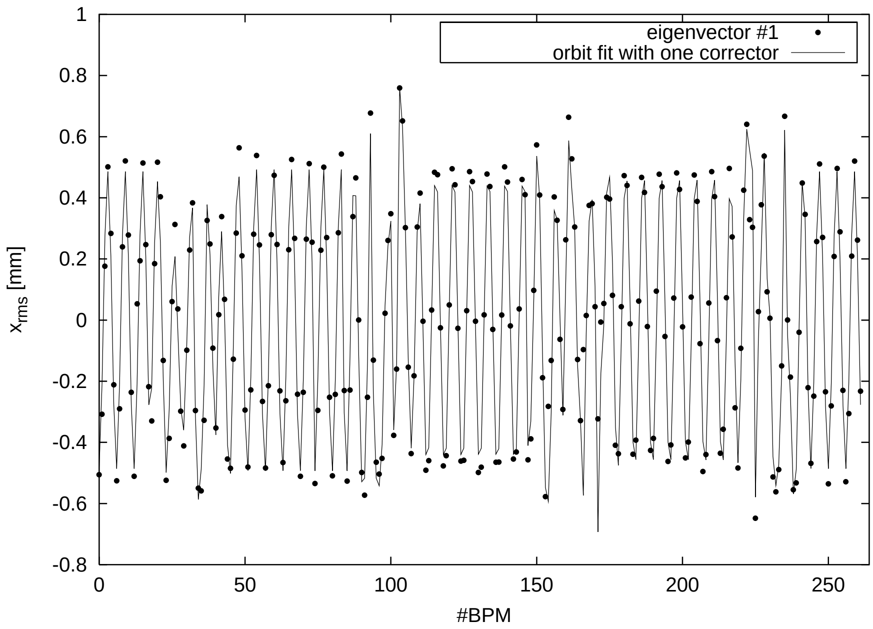

Figure 2: Spatial eigenvector #1 and a fitted orbit, generated by one most effective corrector. The amplitude is scaled by the corresponding rms value in $\mathbf{\Lambda}$.

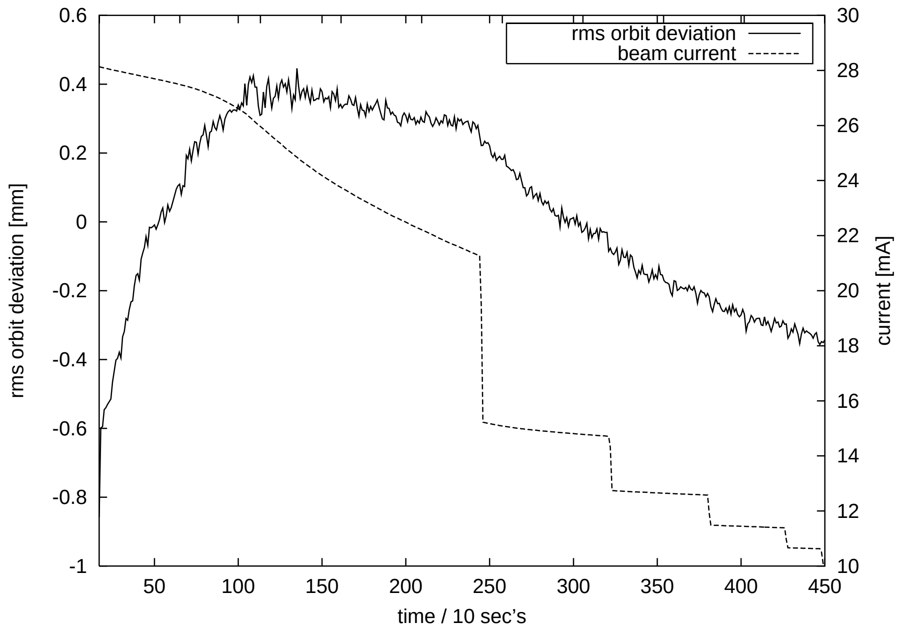

Figure 3: Temporal behaviour.

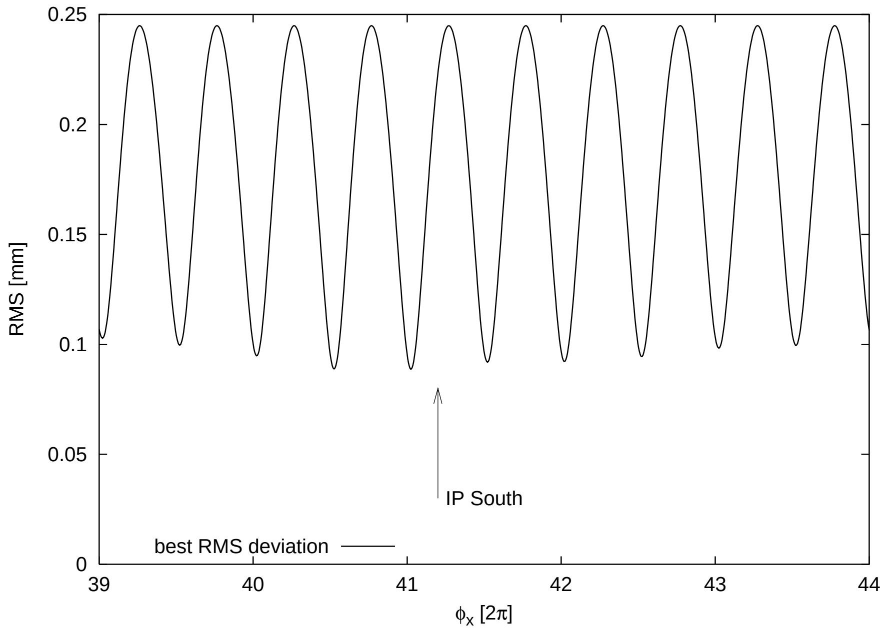

Figure 4: RMS deviation of the fitted orbit to the measured one as a function of the corrector position.

SL7 and SR7 which seem to be very close to the kick, did not work correctly. This results in four nearly equal lowest minima of the RMS deviation curve, which prevents the clear identification of the kick. During the second measurement the above mentioned monitors worked correctly. The curve is shown in Fig. 4. It still exhibits two equal minima which are located very close to the IP, on the left side. The described method suffers from the fact that due to the large number of monitors the difference of placing the kick between two monitors or the next two monitors is relatively small. Therefore we tried a different scheme by fitting only a piece of the spatial vector (typ. 10 monitors) and then shifting this piece monitor by monitor. The betatron oscillation should exhibit a phase jump at the location of the kick and this jump should become obvious by the piecewise fit. Fig. 5 shows three piecewise fitted curves, one left of the IP, one centered around the IP and one right from the IP. Indeed one finds the phases of the curves to shift gradually while crossing over the IP. Unfortunately the two monitors at 7 m from the IP (left and right) do not match one or the other curve better.

3 Orbit Motion and Beam Lifetime

During normal operation and also during our first dedicated measurement rather dramatic beam lifetime reductions were observed, that went away after a wile with decaying beam currents. On the other hand, in other cases with very large

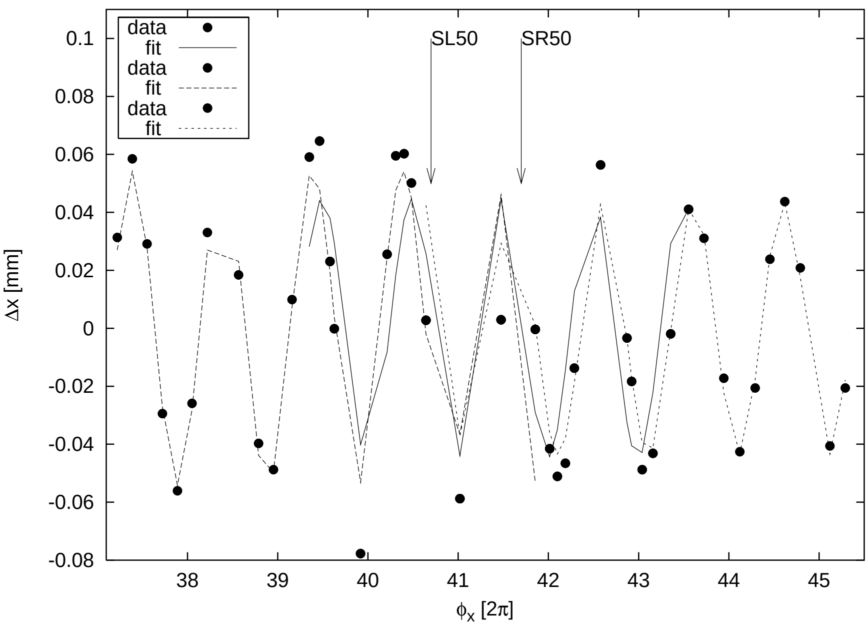

Figure 5: Piecewise fit.

currents, lifetime reductions occurred which did not vanish with decaying current. Those events look like "dust"-events, well known from the pre-NEG pump era. Fig. 6 shows the orbit distortion amplitude together with the beam lifetime vs. time for the first measurement (10/10/98). At the end of the ramp the lifetime was relatively good with 5 hours at 28 mA. But after about 10 minutes it started to decrease and reached its minimum exactly when the orbit amplitude reached the maximum. This coincidence makes it likely that the orbit motion causes the lifetime reduction, at least in this case.

In the second measurement a poor lifetime of about 1 hour was observed as well (Fig. 7). However, this time the lifetime was poor already from the beginning on, and it did not recover to a level of more than 10 hours as in the first measurement. The amplitude of the orbit distortion was even slightly larger than for the other case. Nevertheless there is no correlation between lifetime and orbit amplitude.

In order to find out what caused the lifetime reduction in the first case, the orbit distortion was artificially introduced by turning on a correction coil that most effectively corrects the observed orbit oscillation (SL61 CH). Surprisingly the effect of the kick is rather asymmetric. Turning the coil to one direction leads to a sudden beam loss at a certain amplitude, as one would expect from an aperture limit. However, the other polarity leads to a slow reduction of the lifetime with no sharp boundary. At an rms amplitude of the orbit distortion of ≈ 1.7 mm the lifetime was reduced from 2.5 hours to 1 hour. At the same time an increase of the horizontal beam width was observed on the SR monitor. This could be

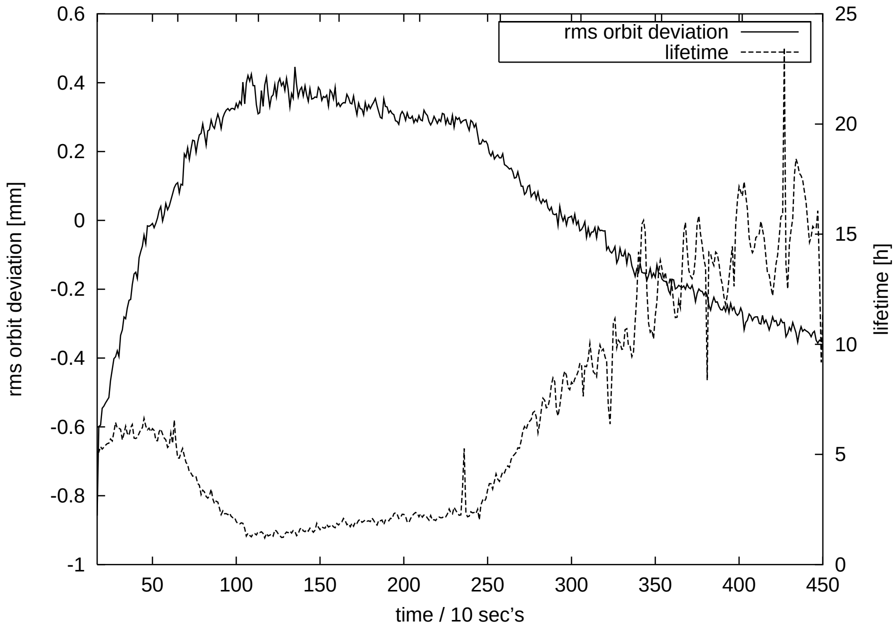

Figure 6: Lifetime and orbit-distortion during measurement 1.

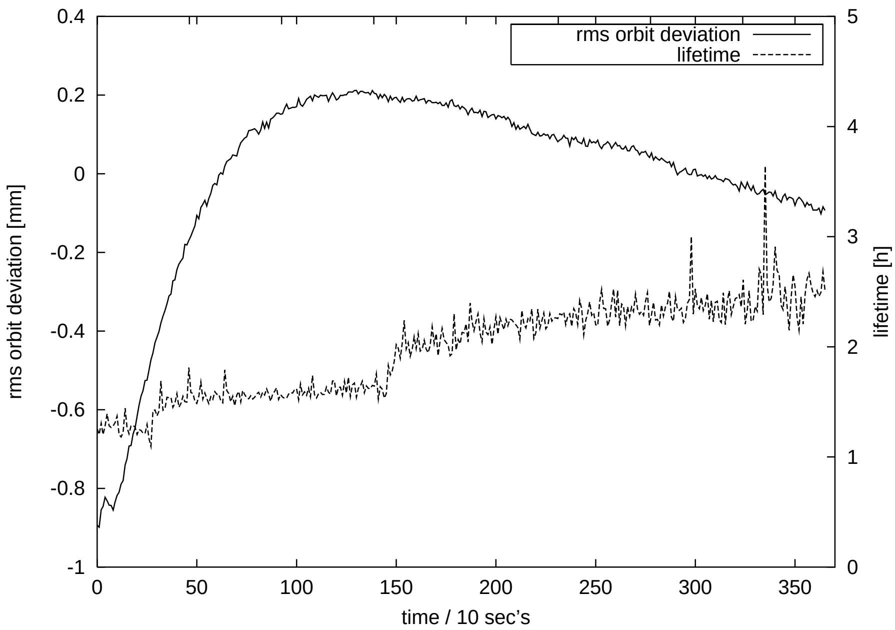

Figure 7: Lifetime and orbit-distortion during measurement 2.

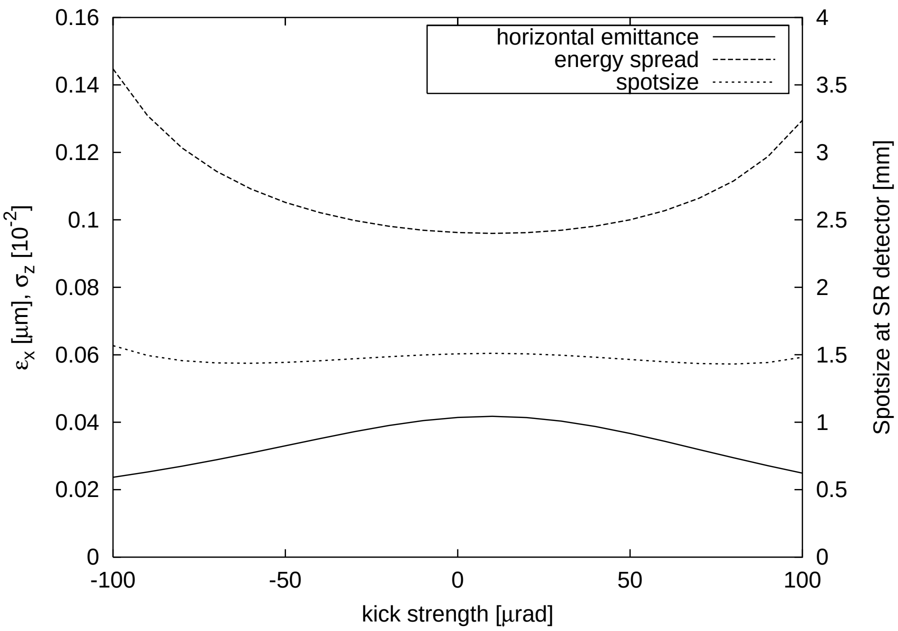

Figure 8: Horizontal emittance, energy spread and predicted spot size at the SR monitor.

interpreted as a modification of the damping distribution of the machine, resulting in a larger emittance, which in turn would explain the smooth lifetime reduction. Note that the 1.7 mm amplitude is not very far from the natural orbit amplitudes, produced by the thermal effect. In order to support this theory a MAD simulation of the impact of a closed orbit distortion by the corrector SL61CH on the damping distribution has been performed (G. Hoffstätter). The result is shown in Fig. 8. It turns out that this kick actually decreases the horizontal emittance. At the same time the energy spread in increased. Since the SR monitor is located at a dispersive position the visible spotsize is a quadratic sum of the beamsize caused by emittance and by energy spread. Unfortunately the two effects cancel roughly, such that the redistribution of the damping partitions would not be visible on the monitor, in contradiction to our observations in the machine.

4 Summary

Significant orbit movements can be observed in HERA-e at higher beam currents. The rms value (averaged over monitors) of the orbit variation changes typically by 1 mm over periods of one or two hours. From an SVD analysis of the orbit data we conclude that only one underlying effect is causing the orbit motion. The shape of orbit amplitude versus time suggests a thermal effect. Supposed that a beampipe would heat up by SR or HOM losses, would bow and take a quadrupole with it, this would explain a beam current dependent orbit kick. In order to explain the observed magnitudes a quadrupole of typical strength would have to move by $\approx 300\,\mu$m. At DORIS such effects are well known and observed orbit amplitudes look qualitatively exactly like ours. Concerning the location of the kick it seems clear that it lies in the IR south. Precise location is difficult with the given data. The best strategy to find the location is probably to equip one by one quadrupole with position sensors and to detect magnet motions directly.

Concerning orbit correlated lifetime reductions we are probably suffering from two distinct effects. One are the traditional HERA-e lifetime problems that exhibit a strong memory effect and are independent of the beam orbit. The other class can be caused by orbit distortions, not unlikely distortions of the magnitude typically observed in normal runs. A possible explanation of the weak dependence of the lifetime on an artificially introduced orbit distortion is a redistribution of the damping partitions. However, the observed change of the beam spotsize on a SR monitor could not be reproduced by a MAD simulation.